E/CONF.39/A/194
29 Oct.1962
ORIGINAL : ENGLISH

UNITED NATIONS CONFERENCE
ON THE APPLICATION OF SCIENCE AND TECHNOLOGY
FOR THE BENEFIT OF THE LESS DEVELOPED AREAS

Agenda Item: A.3.3.1

Denmark

THE DANISH WELL RECORD DEPARTMENT AND THE APPLICATION OF GEOLOGY, GEOCHEMISTRY AND GEOPHYSICS IN THE SEARCH FOR GROUND WATER IN DENMARK

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The Danish Well Record Department and the Application of Geology, Geochemistry and Geophysics in the Search for Ground Water in Denmark

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1. HISTORY AND LEGAL ASPECTS

The first drilling campaign for extraction of ground water in Denmark started in about 1870. Favourable drilling results were obtained in numerous cases, and from about 1900 it was quite common to drill water wells over all of Denmark.

It was soon realized that the data on the subsurface formations and their fluids as known from wells could be generalized in larger or minor areas around the wells. Moreover, valuable assistance in the planning of water wells was occasionally obtained by consulting geologists who had certain knowledge of the nature and distribution of the subsurface formations.

As water consumption increased the legal regulation of the exploitation of ground water became necessary. The first Danish Law concerning Water Supply was proclaimed on the 31st of March 1926. Article 1 of this law determines that all wells drilled for water must be reported to the Geological Survey of Denmark. The well reports should include data on the subsurface formations (particularly aquifers), the ground water table, and pumping tests.

This article forms the legal presupposition of the subsequently established Well Record Department of the Geological Survey. The reasons for the inclusion of the article in the law was the experience that many of the water supply problems related with the apparently fortuitous occurrence of aquifers and the variation of the chemical properties of the ground water might be solved by various geological approaches. Similar views underlie the articles on reporting of boring data to the Geological Survey in the "Law concerning prospecting for and production of raw materials in the sub-surface of the Kingdom of Denmark" of the 19th February 1932 (revised 8th May 1950), and in the "Ministry of Justice decree of 13th August 1939 concerning the drilling of gas wells".

The Well Record Department of the Geological Survey became the depository of all reports on borings, and it accordingly developed into a real subsurface department where all important information on the subsurface and its fluids were filed.

The following brief outline of the geohydrology of Denmark will show some of the problems involved in water supply based on ground water in a humid area. The role of the Well Record Department in the solution of these problems is subsequently sketched.

2. GENERAL HYDROLOGICAL PROBLEMS OF DENMARK

The European part of the Kingdom of Denmark covers an area of 43,042 km^2 with a population of 4.5 millions. The land area consists of the peninsula of Jutland and a number of larger and smaller islands. The rivers are generally small, and practically all water supply is based on ground water. The average water consumption is about 270 l/day/person.

The production of ground water is based on various types of aquifers of which the most important ones are:

a) the White Chalk and the Danian limestone of the upper Cretaceous system,
b) the Greensand limestone of the basal Tertiary,
c) the quartz sands and gravels of the Miocene, and
d) meltwater sands and gravels in the Pleistocene glacial drift.

Practically the entire country is covered with glacial drift, which mainly consists of boulder clay in about one third of the area. This part of the country is inhabited by about one third of the population, and several important cities with industries dependant on water supply are situated in this region. Meltwater sands and gravels occur at random in the boulder clay areas.

The regional dip of the formations at the base of the glacial drift is mainly W and SW. This implies that e.g. the White Chalk and the Danian limestone successively occur at greater depths in going from E to W. These aquifers therefore enter deeper ground water zones, where ascending brines from pre-Cretaceous saltbearing formations or connate water occur. It is accordingly impossible to produce freshwater from the Chalk and the Danian limestone in the main part of Jutland and in several other areas. The Miocene quartz sands and gravels occur in Central Jutland and parts of South Jutland. They may thus to a certain extent act as a replacement of the useless saltwater bearing Chalk and limestone at greater depth.

Apart from the salt water at depth there are several shallow occurrences of salt connate water in marine Pleistocene deposits embedded in the glacial drift, and sea water may infiltrate the aquifers in coastal areas. There are accordingly several hydrological provinces in Denmark, each with its own features.

In summarizing the water supply situation of Denmark we may state the following main problems:

a) Estimate of depth to potential aquifers.
b) Location of irregularly distributed sand and gravel beds in the glacial drift.

c) Estimate of depth to ground water table.
d) Location of salt water occurrences.
e) Evaluation of aquifers.

3. ORGANIZATION OF THE WELL RECORD DEPARTMENT

(a) File of Well Logs.

Graphic logs are traced on the basis of the drilling reports submitted by the well drillers. Many drillers forward samples of the penetrated formations, which are examined by the geological staff of the department and classified in accordance with their lithology, fossil content etc. The drilled sequence is thereafter subdivided stratigraphically in a more or less preliminary way. The waterbearing horizons, water levels and pumping tests are also indicated on the log.

Reference is furthermore made to water analyses if present, and to any special investigations of formations, water properties etc.

The well location is finally plotted on a map to the scale of 1:40,000; 1:20,000 or (in cities) to a larger scale. The well log is furnished with the number of the map and a serial number, which is written at the well location on the map, whereby the log is ready for filing. The logs are filed in accordance with the number system of the maps.

The file of graphic well logs and the location maps form the backbone of the department. By means of this material it is possible to utilize the data available with a minimum waste of time. If information on a certain area is wanted, the map concerned is consulted for well logs on file, the volume with the logs is taken out of the file, and compilation of pertinent information for the special purpose may be started immediately. It is obvious that the density of wells is different in the different areas, and that information was very scanty in many areas, especially in the beginning of the existence of the department. However, even a single well log in an area is extremely useful for a trained geo-hydrologist in estimating ground water conditions.

(b) File of Water Analysis.

The following ions are generally determined in water analysis in Denmark: HCO_3^-, SO_4^{--}, Cl^-, NO_3^-, NO_2^-, PO_4^{---}, Ca^{++}, Mg^{++}, Fe^{++}, Mn^{++}, NH_4^+ and Na^+ ($^+K^+$). Furthermore Oxygen consumption, SiO_2, pH, free CO_2 and hardness degrees are determined. Values are given in milli-equivalents.

The geochemical laboratory of the Geological Survey does some analytical work and collects copies of analyses carried out by commercial laboratories for well owners. All analyses are written on a standard scheme which also includes a graphic column showing the ion content in the water. The analysis cards are filed in the same number system as the well logs and are accordingly as easy available as the logs.

(c) Collection of drilling samples.

Since the final goal of the Department must be the compilation of various sorts of subsurface and hydrological maps, a scientific treatment of the material had to be foreseen from the start of the department.

It is in general impossible to solve all scientific problems during the current daily work which is more or less of a routine nature. A number of studies have, moreover, to be postponed due to lack of sufficient information.

Under these conditions it rather soon proved imperative to build up a collection of formation samples from the drillings for future studies and for reference purposes. The most important samples are therefore kept in storehouses from where they may easily be delivered to the laboratory on short notice.

(d) Water table gauging stations.

The increasing water consumption of the growing cities and industries have resulted in a lowering of the water table and inconveniences for other consumers in many regions. This development has of course important legal aspects, and the need of an objective determination of the variation of the ground water table was accordingly obvious rather early. In 1950 the Geological Survey started observations on the "natural" variation of the water table in about 80 wells in all parts of the country. These wells are preferably located outside the influence of the big water supplies. The gauging is carried out by local laymen, and continuous hydrographic recorders are installed in a few wells.

(e) Geoelectric Resistivity Surveys.

The steady increase of water consumption implied that methods of rational prospecting for aquifers and for the proper location of drillings became more and more desirable. In 1953 geoelectric mapping by means of resistivity measurements were therefore developed with special regard to the geohydrological conditions in Denmark. Geoelectric surveys have since then been carried out in all parts of the country. Three field parties are now at disposal for this kind of work.

4. CONSULTING ACTIVITY AND GROUND WATER PROSPECTING

Immediately from its start in 1926 the department acted as an adviser of water well drillers and water supply engineers in geohydrological matters. At the beginning the department served as an information centre from where the drillers and engineers could obtain more general information on the occurrence of potential aquifers and the over all quality of the ground water in a given region. Landowners and citizenships also often requested the assistance of the department. In practice the advise was either given by correspondance during personal application to the department, or by telephone.

Later, as the amount of data accumulated and the accuracy of forecasts improved for various regions, it became more and more common for well drillers

to ask for drilling programmes. Besides many well drillers currently consulted the department while drilling a well in less known regions regarding the chances of encountering aquifers. Samples of the formations were forwarded at intervals or daily, and after examining the samples the department informed the driller by correspondance or by telephone of the prospects. This service has been utilized rather intensively, and a number of big drilling firms have for years based their bids and work on drilling programmes and forecasts obtained from the Well Record Department of the Geological Survey.

As time went on and the amount of data and the staff of the department increased, it became possible to undertake larger enterprises. Major reports on geohydrological conditions of special regions were prepared as part of regional water supply planning. This work often included extensive field work, compilation of well data and water analyses, and study of the files of cities and industries.

The latest technical improvement of the department was achieved by the establishment of the gauging stations in 1950 and the organization of the geoelectrical section in 1953. The department has since then been fully equipped for rational ground water prospecting under the special geohydrological conditions prevailing in Denmark.

At present a general prospecting programme as carried out for rural or municipal water supplies, industries, and landowners includes the following works:

a) Compilation of geological and hydrological data from the files of the department and from literature for a brief outline of the geohydrology of the area.

b) Planning of a geoelectrical survey if it is impossible to indicate suitable drilling locations on the basis of pure geological evidence.

c) Geoelectrical field work.

d) Preparation of geoelectrical report with recommendations for drilling.

e) Drilling of wells..

The geoelectrical surveys are generally carried out in accordance with the WENNER Method. "Trenching" measurements by which the horizontal variation of resistivity is measured to a constant depth are combined with "vertical" measurements by which the vertical variation of resistivity is determined at selected stations. The results are finally interpreted geologically.

The following three case histories from the start of geoelectric surveys in Denmark show the applicability of the working procedure. More than 100 surveys have since then been carried out. All sorts of projects have been dealt with, including mapping of different formations, structures and salt water occurrences, and determination of depths to formation boundaries, the ground water table and freshwater - salt water contacts.

5. CASE HISTORIES

(a) Landet, island of Taasinge (Rural water supply).

Inhabitants of three villages on Taasinge decided to establish a cooperative waterworks at Landet in 1953. The engineer in charge of the estab-

lishment accordingly enquired the Well Record Department of the Geological Survey regarding a drilling location. It was recommended to drill at a suitable place on low elevation in the valley in which the villages are situated, and which crosses the island from SE to NW.

The valley is assumed to have originated as a subglacial tunnel valley during the last glaciation, and it might, therefore, be suggested that gravel and sand should be present somewhere in the subsurface Pleistocene deposits of the valley. It was the scope to locate such permeable beds which might act as aquifers. The proposed drilling programme included drilling to be discontinued as soon as Tertiary clays were encountered. Further drilling would thence be useless due to the absence of aquifers in the Tertiary beds and the presence of salt water in the Danian limestone below.

Three wells were drilled in different places but they proved all dry, and in each case they displayed practically the same sequence: a series of Boulder clays resting on sticky Lillebelt clay or Rösnæs clay of the Eocene. The Eocene beds were encountered at about 40 m below surface.

The subsequently planned resistivity survey included vertical measurements at each of the dry holes and a resistivity mapping ("trenching") of the glacial drift using an electrode spacing of 50 m and covering about 1 1/2 square kilometres of the valley bottom.

Very low resistivity values were obtained in the area, and it was obvious from the resistivity curves that the Tertiary Lillebelt and Rösnæs clays had very low resistivities.

The iso-ohm map displayed two maximum anomalies, one over elevated ground on the northern slope of the valley with the highest resistivity values, and another one on the bottom of the valley N of Landet church. The last-named was interpreted as suggestive of gravel and sand accumulations in the glacial drift. The possibility of the high resistivity being indicative of partly dry beds above the groundwater table could be disregarded since the valley is very level over the area concerned, and the groundwater table could be assumed to be very near the surface. It was finally recommended to drill a well in the center of this anomaly.

A shallow sand and gravel deposit was encountered under 1 m of soil and clay, and a screen was set in relatively coarse sand and gravel from 18.4 to 25.4 m below surface. The water table was at the surface, and the yield of the well was 10 cubic m/h at a draw down of 3 m.

(b) Marslev Dairy (Local water supply).

The dairy needed more water for the manufacturing of milk products than its wells could produce in 1953. A new well did not succeed in finding water-bearing beds in the Pleistocene, which was penetrated at 35 m and underlain by Paleocene clays. Moreover, the Paleocene beds proved to be salt water bearing from a depth of 46 m. After this failure the proprietor requested the Geological Survey to make a resistivity survey of an area near the dairy.

The area concerned was covered with 50 m trenchings in order to register the drift resistivities. A broad maximum which extended toward the dairy was defined south of the dairy. Drillings were recommended at an extension of the

maximum near the dairy. Four wells were drilled. Each of the wells proved the presence of sand and gravel beds and the capacities of wells no. 1, 3 and 4 were from 21 to 24 m^3/h at 3.5 m depression of the water table. The log of well no. 1 was as follows:

File no. 146.197.a. Marslev Dairy.

0-11.5 m Fine melt-water sand, argillaceous
11.5-14.5 m Melt-water clay
14.5-16.5 m Melt-water sand and gravel, waterbearing
16.5-17.0 m Boulder clay, not penetrated.
Water table 1.5 m below surface.

(c) Rislev. (Salt water occurrence).

HEE ANDERSEN and ODUM mapped an inland occurrence of salt marsh plants in the bog Slagmose at Rislev in 1923. Subsequently drilled wells encountered shallow Bryozoan limestone at about 8 m depth with salt water of 1.033% NaCl in the center of the bog.

The bog was made the object of a resistivity survey in 1953 which aimed at investigating the salt water occurrence. Trenchings with a=25 m a=50 m and some vertical measurements were planned. During the course of the survey it turned however out to be impossible to obtain readings with an electrode spacing of 50 m, and it was, therefore, necessary to confine the study to a 25 m mapping and a single vertical measurement.

The iso-ohm map showed a very simple pattern with the lowermost resistivity found in the center of the bog being the center also of the area of the salt marsh plants as outlined by HEE ANDERSEN and ODUM in 1923. The resistivity minimum may mainly be related to the salt water which ascends from the deep subsurface to the surface of the bog. The salt water may thus be the overwhelming factor affecting apparent resistivity in the area according to this interpretation.

The iso-ohm contours were almost conformable with the contours of the surface topography around the bog basin, which might be indicative of continuous increase of hydrostatic deficit in the low lying area of the bog from the margin of the basin to its center, due to natural drainage of the ground water and corresponding increase of elevation of the salt water in the subsurface.

6. DEVELOPMENT OF STAFF AND ACTIVITY

A very brief statement regarding the staff and growth of the department might be of interest in the present connection.

Development of staff	1926	1934	1942	1950	1961
Geologists	1	2	3	6	11
Chemists	1	2	2	2	4
Geophysicists					2
Assistants				1	3
Draftsmen					3
Office personnel				1	4
	2	4	5	10	27

Consulting, reports on wells, samples and geoelectric surveys.

	1926	1934	1942	1950	1961
Consultings	30	202	166	503	914
Reported wells	379	826	1535	2213	2460
Rock samples	x)	x)	x)	12644	14325
Geoelectric surveys	+	+	+	+	23

x) not recorded

It has been a leading principle to publish papers on special subjects as: subsurface geology, hydrology, geochemistry of ground water, geophysics, structure etc. at intervals. The basic idea is that consulting activity has to be followed up by research in order to improve the service to the public. The work of the staff may accordingly be subdivided in the following three main categories:

a) Routine work
b) Consulting
c) Scientific research.

Each of these categories covers about one third of the working capacity of the department.

It should be added that the department now deals with practically all subsurface matters including hydrology, mineral deposits, hydrocarbons etc. Geohydrology is however still the most important part of its work.

7. APPLICABILITY TO OTHER AREAS

The intention with this brief outline of the history and activity of the Well Record Department of the Geological Survey of Denmark has been to show that a general file on subsurface geology and hydrology is the basic presupposition of rational ground water prospecting.

The geohydrological conditions may change from place to place. There is, however, no doubt regarding the adequate approach to their solution. The ground water problems must be treated with geological methods in which geochemistry and geophysics have to be included as aiding tools.

The developments in Denmark have proved that even a small staff of well experienced geologists and chemists may contribute considerably to the solution of regional and local ground water problems if they systematically accumulate data from wells from the beginning. It is, however, very important to keep in mind, that each region has its particular problems, which need scientific consideration and research in a major or minor degree. Current research is therefore absolutely necessary.

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